Effects of Iron Conduits On Line Drop

C. E. Moran
Wallace McCrackin

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AN INVESTIGATION OF THE EFFECTS OF IRON CONDUITS ON LINE DROP.

A THESIS

PRESENTED BY

C·E·MORAN **WALLACE McCRACKIN**

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

C. E. Freeman
Per J. E. Snow

CHICAGO, JUNE, 1906.

Howard M. Raymond.
Dean of Engineering Studies

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INTRODUCTION

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It has become customary in electrical wiring to use iron conduits, through which conductors are run, this system being used for wiring houses, office buildings, etc., for both lighting and motor loads. This arrangement insures protection against fire which might result from crossed wires if the circuits were exposed and also protects one circuit from another and from external injury and also gives a more compact and neater appearance to the wiring. While this plan has many advantages, the question of economy must also be considered. If it should be found that this arrangement would cause a considerable energy loss each year, it would not be economical to use this; therefore, it is the purpose of this Thesis to ascertain definitely, just how great a drop in voltage is caused by the use of conduit, if there be any additional drop besides ohmic drop. This being found from other data the energy loss per year can be calculated.

When an alternating current is used for distributing energy it is not sufficient to regard the ohmic loss as the only one which occurs, as there is another due to the factor known as reactance, which is made up of both inductance and capacity of a circuit. When the circuit is short the capacity

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effect is negligible, while the inductive effect may be large. The inductance of a circuit depends upon the enrgy of the magnetic field which is set up by the current flowing through the conductors. The effect of this magnetic field is to set up an induced E.M.F. in a conductor, which will be opposite in direction to the impressed E.M.F. and will therefore cause the latter to be reduced in effective value. When the wires carrying the current are placed in close proximinity and arranged so that the current flows in opposite directions, with the two conductors lying side by side, a very weak magnetic field is produced in the surrounding region, since the fields set up by the two conductors tend to neutralize each other. If the conductors are placed in an iron conduit, since the permeability of iron is much greater than that of the air, the strength of the magnetic field surrounding the conductors will be greatly increased, but since the same current is flowing through both conductors, and the two fields oppose each other, the increase in field strength, will have no effect upon the inductive drop.

The magnitude of the inductive drop will depend upon the distance the wires are apart, for the closer they are together the more the fields neutralize each other, and the smaller the inductive drop. Theoretically, the drop would never be zero except when the conductors are concentric, when the fields would be exactly opposed. This condition is approximated closely however, in the No. 14 twin wire and in the No. 6 wire, the conductors lying close together in the conduit.

In the series of tests which we have made the wires were arranged in the usual manner, which is customary in practice, so as to make the results of the greatest practical value.

APPARATUS

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The apparatus used in this test consisted of the following machines and instruments:

To supply the current used in the test a 45 K.W., 1100 Volt Single Phase Westinghouse Generator was used, which at the normal speed of 1000 R.P.M. gave sixty-six alternations per second. This machine was connected by means of belting and a counter shaft, to a 30 H.P., 110 Volt, 4 Pole Westinghouse D.C. Motor. In order to obtain the necessary speed regulation, a 15 K.W., 125 Volt, 4 Pole Westinghouse D. C. Generator was connected in series with the 30 H.P. motor as a depressor. This generator was direct connected to a 26 H.P., 115 Volt, 4 Pole Crocker-Wheeler D.C. motor, with a normal speed of 1025 revolutions per minute.

The exciting current for the alternator was obtained during part of the test from a motor-generator set similar to that used as a depressor. For the lower frequencies, where the exciting current was much higher than normal a 110 Volt Bipolar C. and C., D.C. generator was connected in series with the 110 Volt lines, giving an approximate voltage across the fields of 220 Volts. The C. and C. machine was direct connected to a 6 H.P., 110 Volt, 4 Pole Stow Motor.

For stepping down the voltage from the 1100 volt alternator used, two 5 K.W., 1050 - 210 - 420 Volt Westinghouse

transformers were used in the test on the No. 14 twin wire. The transformers were connected with their primary windings in parallel and the secondarys also in parallel, with the connections so made as to give 210 Volts on the latter. For the test on the No. 6 single wire three 5 K.W. Westinghouse and one 5 K.W., 1100 - 110 - 220 - 440 Volt G. E. transformer were used, both the primary and the secondary windings being connected in parallel, with 210 Volts on the secondary.

The instruments used in the test on the No. 6 wire consisted of the following:

	Weston A.C. Voltmeter # 5091
(0 - 60, 0 - 120); ----------	Weston A.C. Voltmeter # 3484
(0 - 12, 0 - 24); ----------	Thompson A.C. Ammeter #24081
(0 -200);-----------	Weston A.C. Wattmeter # 1778
(0 - 7.5, 0 - 15); ----------	Weston A.C. Wattmeter # 512
(0 - 15 , 0 - 30).	

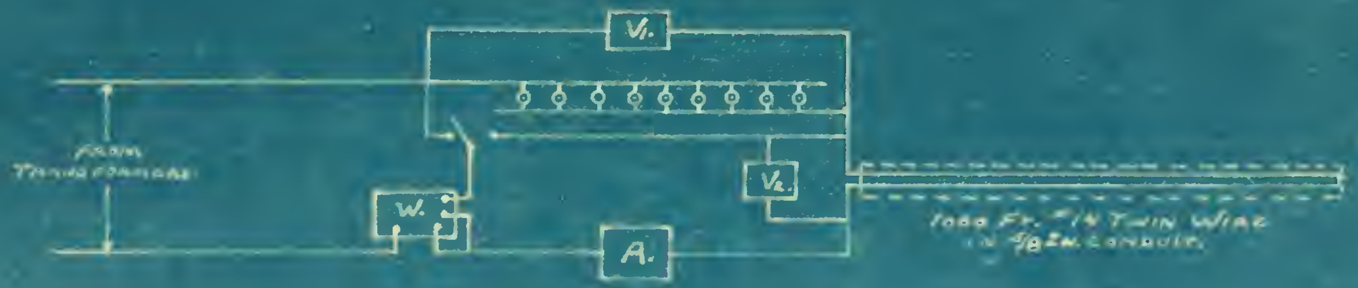
For the test on the No. 14 wire the following instruments were used:

Weston A.C. Voltmeter, --	# 5091	(0 - 60,	0 - 120);
Weston A.C. Voltmeter, --	# 5246	(0 -125,	0 - 250);
Thompson A.C. Ammeter, --	#51467	(0 - 50	);
Weston A.C. Wattmeter, --	# 1778	(0 -7.5,	0 - 15).

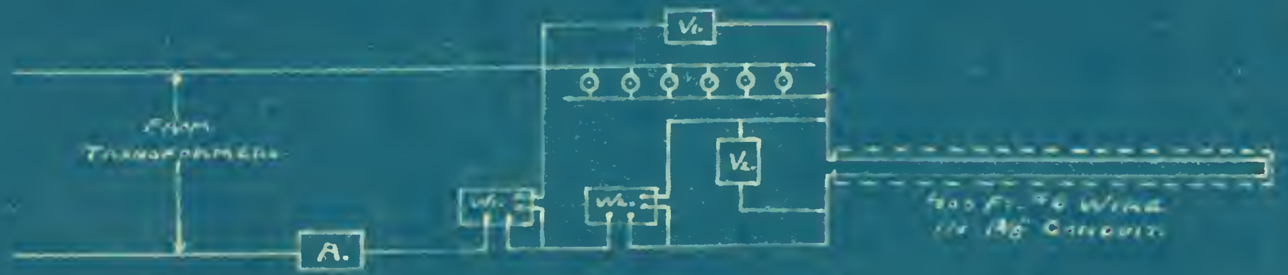
In addition to the above instruments several voltmeters were used temporarily in obtaining roughly the voltage the depressor, exciting sets, etc. The speed of the alternator was obtained by means of a ball tachometer attached directly to the shaft and connected to a (0 - 5) Weston D.C. Voltmeter. This was calibrated by means of a speed counter.

An incandescent lamp rack was used as a load for the alternator, thus doing away with any inductive effects that would be introduced if a motor or arc light load was used.

The wire used was of two sizes, No. 14 twin wire and No. 6 single wire, these being the sizes most used in practical work. For the test on the No. 14 wire, one thousand feet of this wire and one thousand feet of five eights inch iron conduit, in ten foot lengths, was used. For the test on the No. 6 wire, four hundred feet of this wire and two hundred feet of one and three eights inch iron conduit, in ten foot lengths, was used. These two sizes of conduit are those mostly employed in practical work with the size conductors we used.



Scheme #1.



Scheme #2.

METHOD

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The first test was made on the No. 14 twin wire. One thousand feet of this wire was drawn through the five eights inch conduit, which was arranged in ten foot lengths upon a supporting rack. The farthest ends of the wire were connected together so that the current returned upon itself through the pipe and at any instant a current was flowing in both directions in each pipe.

The various instruments were arranged as shown in Scheme No. 1. The load, an incandescent lamp rack, was placed ahead of the pipes instead of beyond them, as is the case in practice, merely as a matter of convenience, the effect being exactly the same. A (0 - 125, 0 - 250) Weston A.C. Voltmeter, V2, was used to obtain the drop across the wire in the conduit, and A (0 - 60, 0 - 120) Weston A.C. Voltmeter V1, was used to obtain the drop across the lamp rack, this being kept constant at one hundred and ten volts. A (0 - 50) THOMSON A.C. ammeter was used to measure the current flowing, and A (0 - 7.5, 0 - 15) Weston A.C. Wattmeter was used to measure the power consumed. This Wattmeter was so connected through the switch S., that it measured either the power consumed in the wire alone or the total power used up in the wire and the load.

In order to obtain the effect due to change of fre-

quency, a series of runs were made at frequencies of sixty, fifty forty and thirty cycles per second, the method of procedure being the same for all frequencies. The generator was first brought to the required speed by varying the speed of the motor driving it. The field current was then thrown on and adjusted until the drop across the lamp rack was one hundred and ten volts. A load was then put on the machine, and the speed and drop across the load being kept at their normal values, the readings of the various instruments were taken. The load was taken in approximately five ampere steps up to twenty-five amperes. A set of readings having been obtained for each frequency in this manner, another set was taken as a check.

The wire was then drawn out of the conduit and looped loosely upon the supporting rack, and the test repeated in order to determine the relative effect when the wire was in and out of the conduit.

The second test was made on the No. 6 single wire, four hundred feet of which was drawn through two hundred feet of the one and three eights inch conduit, so that the current returned upon itself in each pipe.

The arrangement of the various instruments is shown in Scheme No. 2. This is practically the same as Scheme No. 1, the only difference being that two wattmeters were used instead of one, W., measuring the power loss in both the wire and the load, while W_2 measured only the power consumed in the wire.

The method of proceedure was the same as in the first test, runs being taken at frequencies of sixty, fifty, forty and

and thirty cycles per second, both with the wire in and out of the conduit. The load used, however, was much larger than with the No. 14 wire, running up as high as ninety-five amperes. A series of runs having been made with the wire in the conduit, it was withdrawn and looped loosely upon the rack and another series of runs made so as to compare the effects.

During the tests the temperature of the wires was kept as constant as possible, for as the wires heat up, as they do when the load is increased, the resistance will rise, causing a corresponding increase in the voltage drop across the wires. In order to correct for this a heavy current was sent through the wires before each test so that their temperature was raised and this temperature was then kept as constant as possible during the test. Of course, this caused the voltage drop obtained to be larger than normal, but it had no effect upon the relative drops obtained with the wire in and out of the conduit, which was the object sought in making the test.

The currents used in the two sizes of wires were considerably greater than the normal currents used in practice. The current carrying capacity of No. 6 single wire is usually taken at 50 amperes and for No. 14 twin wire is taken at 12 amperes. The maximum currents used in our test were 95 amperes for the No. 6 wire and 25 amperes for the No. 14 wire. Of course these large currents were flowing for a few minutes only.

EXPLANATION OF CURVES

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The curves, in each case, were plotted with the load in amperes as abscissas and volts drop across the wire as ordinates. A curve was drawn for the results obtained at each frequency, both with the wire in and out of the conduit. A general curve sheet was plotted for each size wire showing the relation of the curves obtained at the different frequencies to each other. Curves were also drawn showing the effect of frequency on the drop at constant load, with cycles per second as abscissas and volts drop as ordinates.

Each instrument used was calibrated and a calibration curve drawn, with true amperes, or volts, as abscissas and indicated amperes, or volts, as ordinates. The original data obtained was corrected by means of these curves and the corrected values used in plotting the curves for the different tests.

DISCUSSION

--------oOo--------

The use of the iron conduit in wiring, brings in the question of whether this conduit, because of its high permeability as compared with air, does cause a drop in addition to the ohmic drop which exists. This system of wiring has many advantages, and if it can be shown that there is no loss in voltage due to it, another point in favor of its universal adoption will be established. A year ago, at Armour Institute, a test of this system was made, the amount of material being so small, that it was hard to obtain accurate results. This year, a large enough length of wire and pipes were obtained so as to enable the drop to be measured accurately, if there were any drop in voltage, also if any variation of drop due to change of frequency were present, this length should be sufficient to enable us to detect it. However, after eliminating the effect, due to a change in resistance, caused by a variation of temperature, and after taking many sets of data, and plotting curves, the conclusion was finally reached that there was no appreciable drop due to the presence of the conduit or to change of frequency.

The results were so consistent that no doubt could exist as to a chance for error, and if any drop does exist, it must be so small that it cannot be measured by ordinary instruments used in practice.

Therefore, this drop is so small that any loss of energy due to it would be more than counterbalanced by the advantages obtained by the use of this conduit.

D A T A

No. 6 Wire in Pipes

$f = 60.$

I.	V_1	V_2	W_1	W_2
24	110	5.05	2.9	.12
38.5	110	7.16	4.5	.25
54.25	110	10.18	6.45	.5
78.8	110	15.0	9.8	1.2
95	110	18.25	11.6	1.75

$f = 60$

I.	V_1	V_2	W_1	W_2
32	110	6.13	3.85	.18
43	110	8.0	5.0	.3
63	110	11.75	7.65	.72
78	110	14.27	9.6	1.13
94.5	110	18.17	12.15	1.75

DATA

:::::::

No. 6 Wire in Pipes.

$f = 50$

I.	V_1	V_2	W_1	W_2
21	110	4.42	2.5	.095
34	110	6.05	3.9	.22
61	110	11.54	7.4	.74
74.5	110	14.27	9.2	1.08

$f = 50$

I.	V_1	V_2	W_1	W_2
26	110	4.95	2.85	.15
38	110	7.15	4.4	.28
48	110	8.81	5.6	.42
61	110	11.33	7.2	.65
84	110	16.30	10.6	1.4
92	110	17.67	11.8	1.68

$f = 40$

I.	V_1	V_2	W_1	W_2
25	110	4.85	2.95	.14
37	110	6.9	4.4	.23
50.3	110	9.17	5.9	.46
70.5	110	13.12	8.6	.95

$f = 40$

I.	V_1	V_2	W_1	W_2
24	110	4.6	3.0	.15
38.1	110	7.0	4.3	.28
48	110	9.05	4.8	.43
65.7	110	12.25	7.5	.85
81.5	110	15.15	9.8	1.26

DATA

No. 6 Wire in Air

f = 60

I	V_1	V_2	W_1	W_2
24	110	4.60	2.7	.105
36	110	6.77	4.3	.25
50	110	9.37	6.0	.45
69	110	13.0	8.5	.92
77	110	14.50	9.5	1.15
95	110	18.42	12.45	1.82

f = 60

I	V_1	V_2	W_1	W_2
24	110	4.65	2.8	.15
37.5	110	6.89	4.3	.22
49.6	110	9.28	5.85	.42
77.2	110	14.5	9.5	1.05

f = 50

I	V_1	V_2	W_1	W_2
21	110	4.25	2.5	.07
35.5	110	6.65	4.2	.2
45.2	110	8.43	5.3	.35
91	110	17.15	11.5	1.5

f = 50

I	V_1	V_2	W_1	W_2
19	110	3.9	2.3	.06
35	110	6.56	4.1	.2
45.5	110	8.43	5.3	.35

DATA

No. 6 Wire in Air

$f = 40$

I	V_1	V_2	W_1	W_2
24	110	4.6	2.8	.15
54	110	6.56	4.1	.2
50.3	110	9.4	5.9	.45
56.5	110	10.72	6.8	.55
80.5	110	15.15	9.9	1.15

$f = 40$

I	V_1	V_2	W_1	W_2
24	110	4.6	2.8	.18
50	110	9.37	5.87	.45
76.5	110	14.3	9.5	1.10

$f = 30$

I .	V_1	V_2	W_1	W_2
25	110	4.8	2.8	.12
36.5	110	6.83	4.2	.21
51.7	110	9.28	6.1	.4
65.8	110	12.27	7.8	.75

DATA

No. 14 Wire in Pipes

$f = 60$

I	V_1	V_2	W_1	W_2
3	110	26	.6	.078
9.1	110	62	1.65	.565
15.5	110	97	3.2	1.50
17.6	110	108	3.85	1.85
24.1	110	145	6.05	3.4

$f = 60$

I.	V_1	V_2	W_1	W_2
3.25	110	29	.6	.078
5.25	110	36	.78	.205
13.25	110	87.2	2.9	1.15
23.25	110	138	5.6	3.05

$f = 50$

I.	V_1	V_2	W_1	W_2
4.5	110	33	.67	.08
7.0	110	49	1.15	.2
13.6	110	88.7	2.64	1.0
22.1	110	136.5	5.5	2.95
25.0	110	152	6.2	3.5

$f = 50$

I	V_1	V_2	W_1	W_2
5	110	37	.76	.082
9.2	110	60	1.65	.45
11.5	110	72.2	2.1	.75
18.9	110	115.7	4.25	2.1
24	110	146	6.0	3.4

DATA

No. 14 Wire in Pipes

$f = 40$

I.	V_1	V_2	W_1	W_2
4.5	110	35	.55	.078
10.5	110	68.8	1.9	.57
13.6	110	87.0	2.74	1.05
20	110	125	4.74	2.45
25	110	152	6.2	3.6

$f = 40$

I.	V_1	V_2	W_1	W_2
3.5	110	32	.57	.078
6.8	110	50	1.3	.20
15.8	110	99	3.33	1.45
22.2	110	137	5.4	2.95
20.0	110	125.5	4.65	2.4

$f = 30$

I.	V_1	V_2	W_1	W_2
3.5	110	32	.55	.078
9.5	110	63.5	1.65	.45
13.65	110	87.5	2.74	1.05
19.7	110	122	4.3	2.2

$f = 30$

I.	V_1	V_2	W_1	W_2
3.5	110	32	.57	.078
6.85	110	50	1.1	.2
11.3	110	74	2.05	.72
20.25	110	125	4.75	2.5

DATA

No. 14 Wire in Air

$f = 60$

I.	V_1	V_2	W_1	W_2
6.	110	41.9	1.05	.78
7.9	110	52.8	1.4	.95
13.25	110	83.7	2.74	1.5
17.5	110	108.5	3.97	2.0
21.7	110	132.	5.35	2.4

$f = 50$

I.	V_1	V_2	W_1	W_2
4.5	110	35.2	.56	.08
11.3	110	73	2.0	.72
17.7	110	110.1	3.9	1.87
20.1	110	123	4.72	2.39
20.5	110	126	4.78	2.52

$f = 40$

I.	V_1	V_2	W_1	W_2
5.1	110	40	.80	.1
8.9	110	61.8	1.55	.51
15.85	110	100.2	3.4	1.48
19	110	117	4.35	2.15

$f = 30$

I.	V_1	V_2	W_1	W_2
7.15	110	50	1.2	.22
10.4	110	69.1	2.32	.85
12.8	110	82.9	1.91	.61
18.8	110	117.9	4.24	2.15

CALIBRATION OF INSTRUMENTS

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Weston Voltmeter #5091

Standard	Instrument:
30	29
40	39.2
50	50.1
60	59.5
70	69.7
80	79.9
90	89.9
100	99.9
110	109.9
120	120

Weston Voltmeter #5246

Standard	Instrument:	
30	29	31
40	39	40.9
50	49.4	50.8
60	59.2	60.8
70	69.7	70.8
80	81	82
90	89.6	91
100	100	100.8
110	109.9	110.5
120	120.3	120.8

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Weston Voltmeter #3484

HIGH SCALE

Standard	Instrument:
10	10
12	11.98
14	13.97
16	15.92
18	17.88
20	19.83
22	21.82
24	23.82

Weston Voltmeter #3484

LOW SCALE

Standard	Instrument:
2	2.1
4	4.05
6	5.93
8	7.97
10	9.83
12	11.89

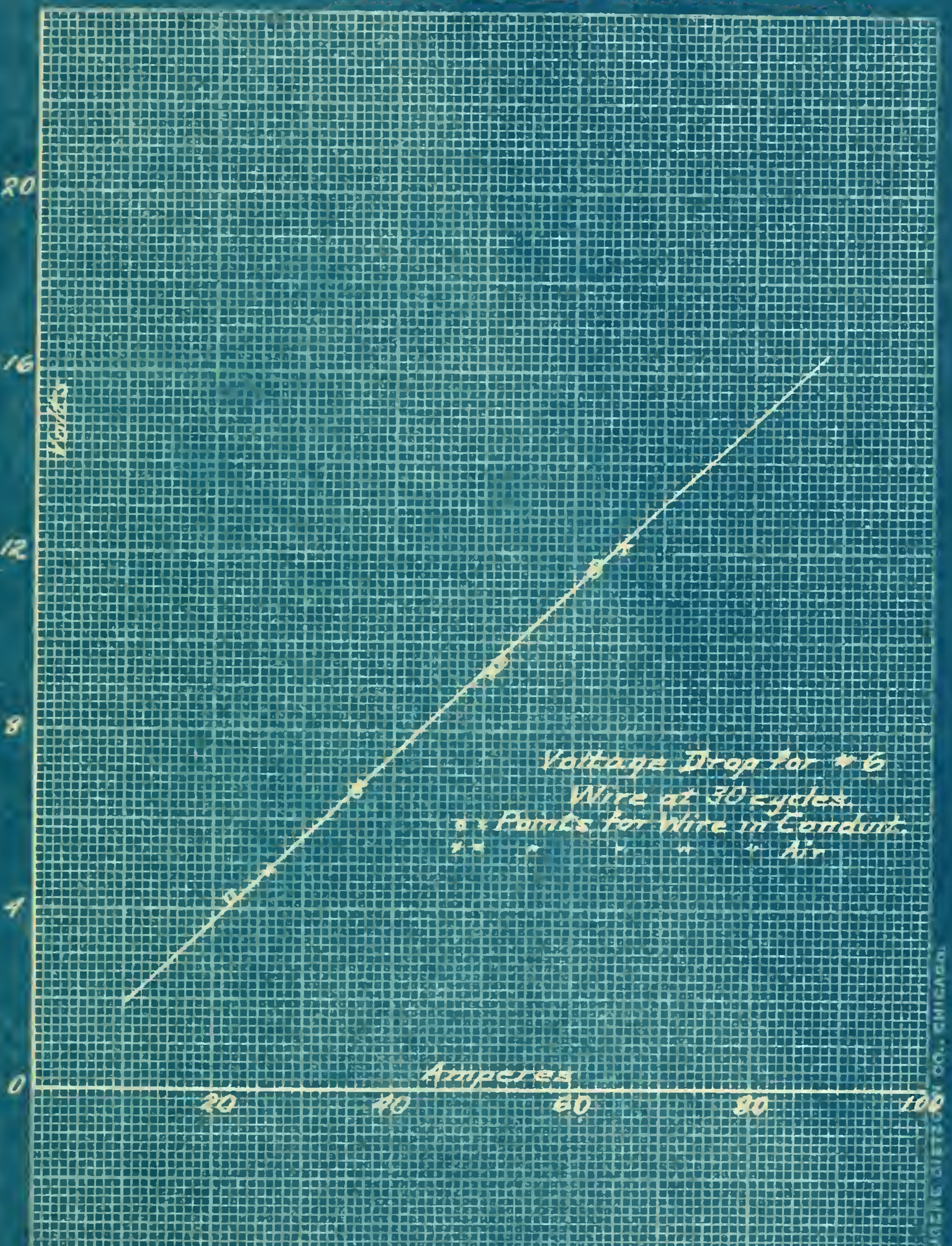
CALIBRATION OF INSTRUMENTS

Thomson Ammeter #51467.

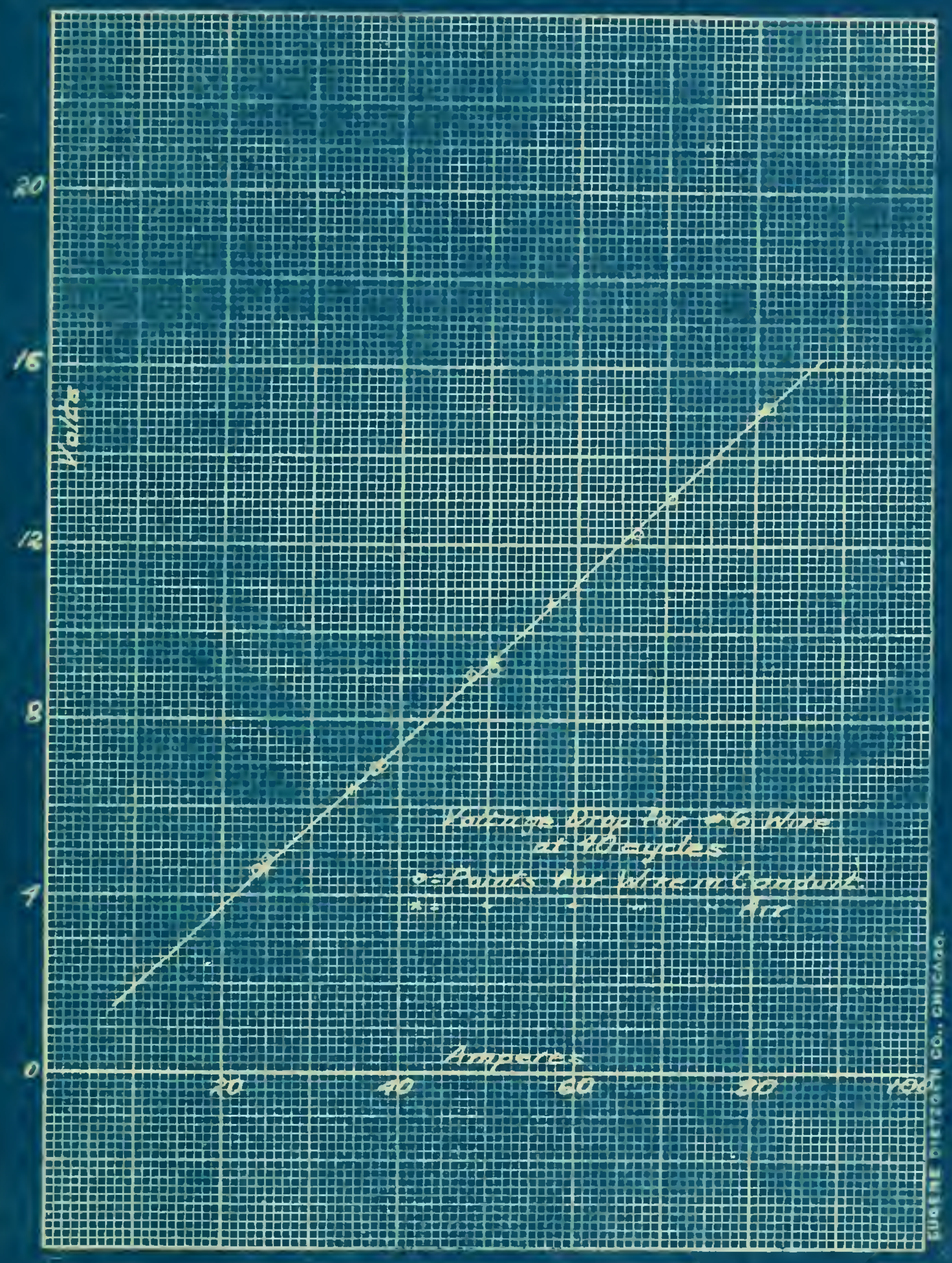
Standard	Instrument
5	7.38
10	11.3
15	16.1
20	21.4
25	26.4
30	31.4
35	36.0
40	40.7
45	45.5
50	51.4

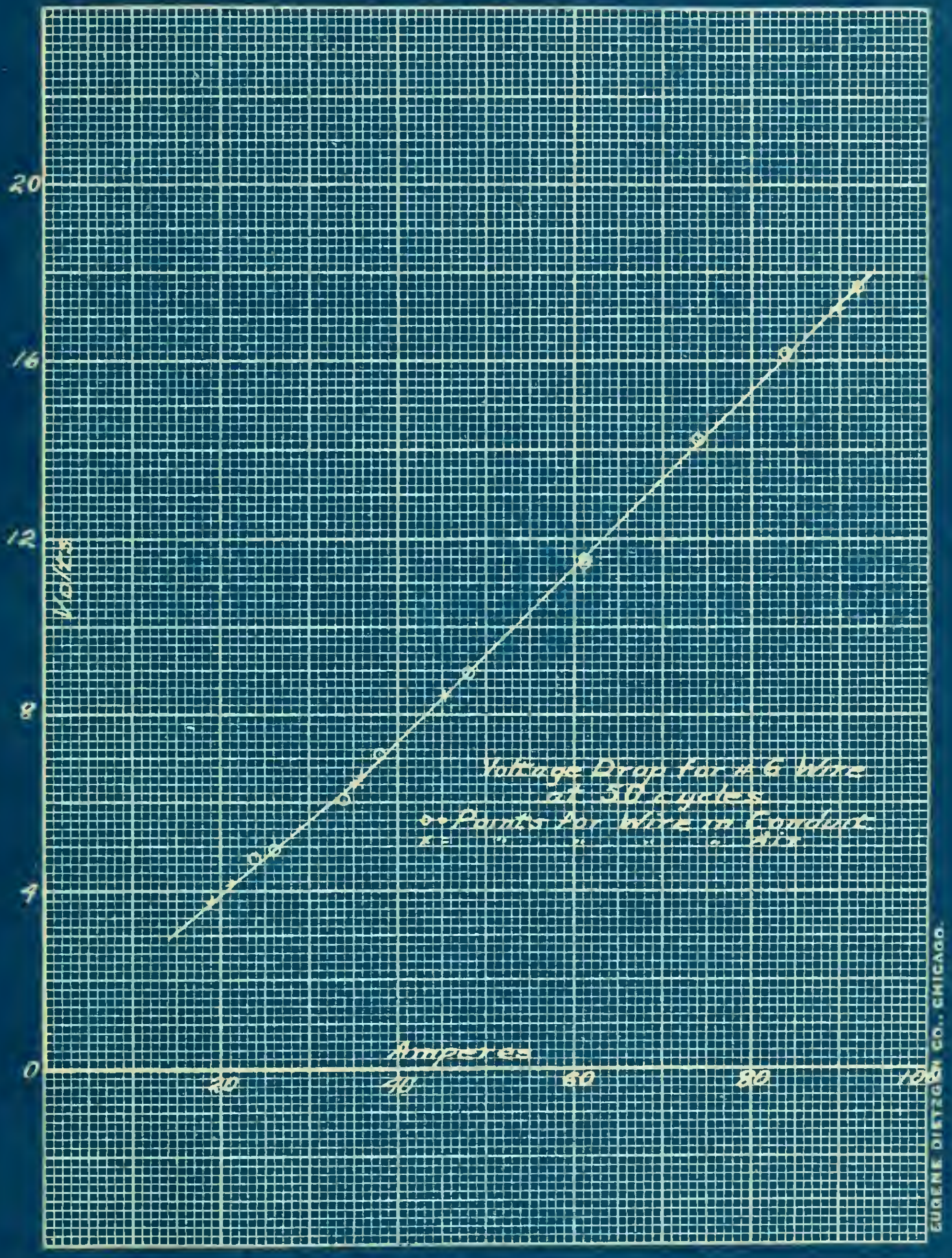
Thomson Ammeter #24081.

Standard	Instrument	
20		24.8
30	25	36
40	36.4	46.9
50	48	56.3
60	58.2.	66.4
70	68.9	76.9
80	79.3	86.2
90	87.2	96.25
100	99.1	105.9
110	108.9	115.1
120	118.3	124
130	128.25	132.9
140	138.1	104.9
150	148.2	

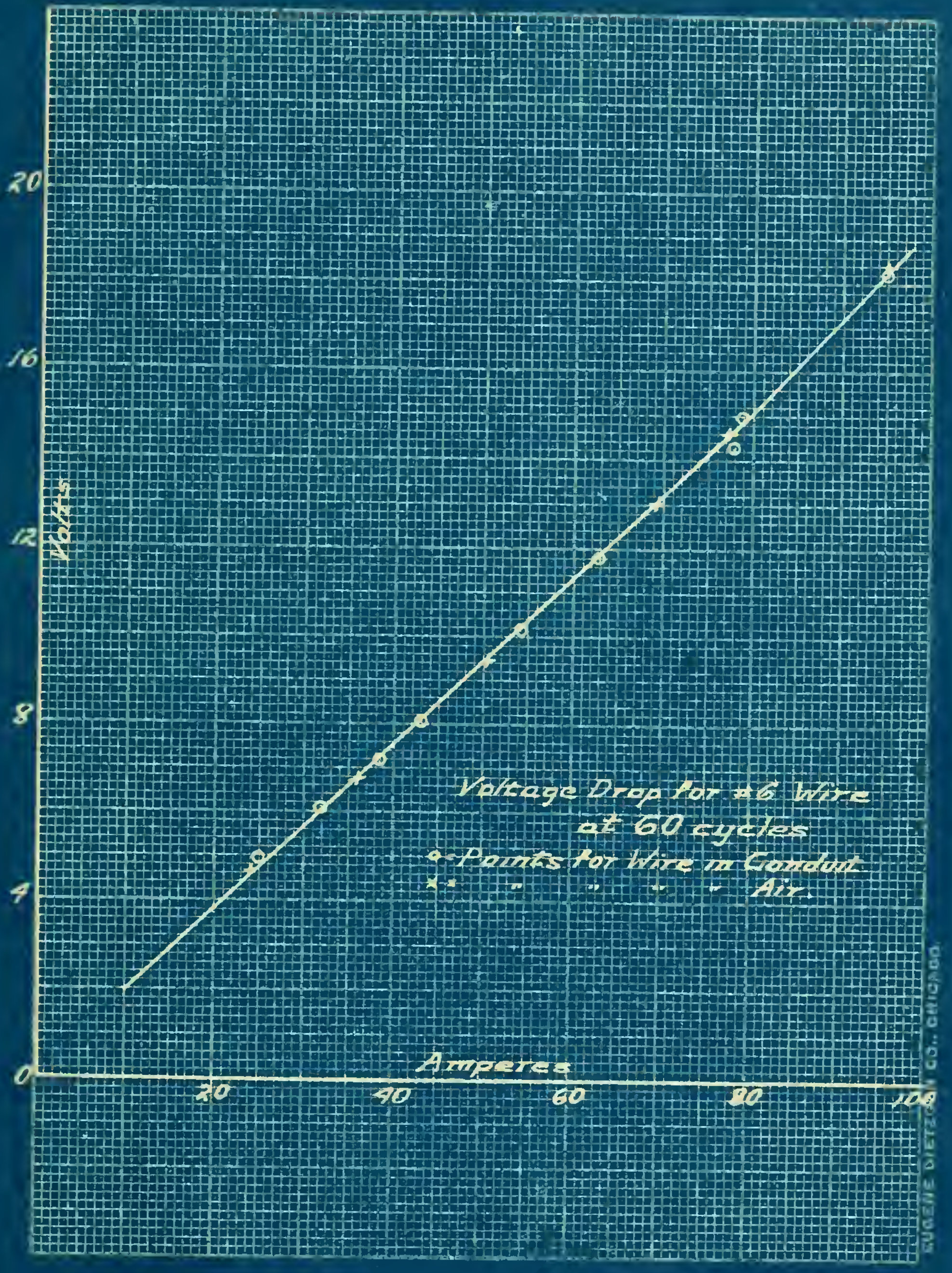


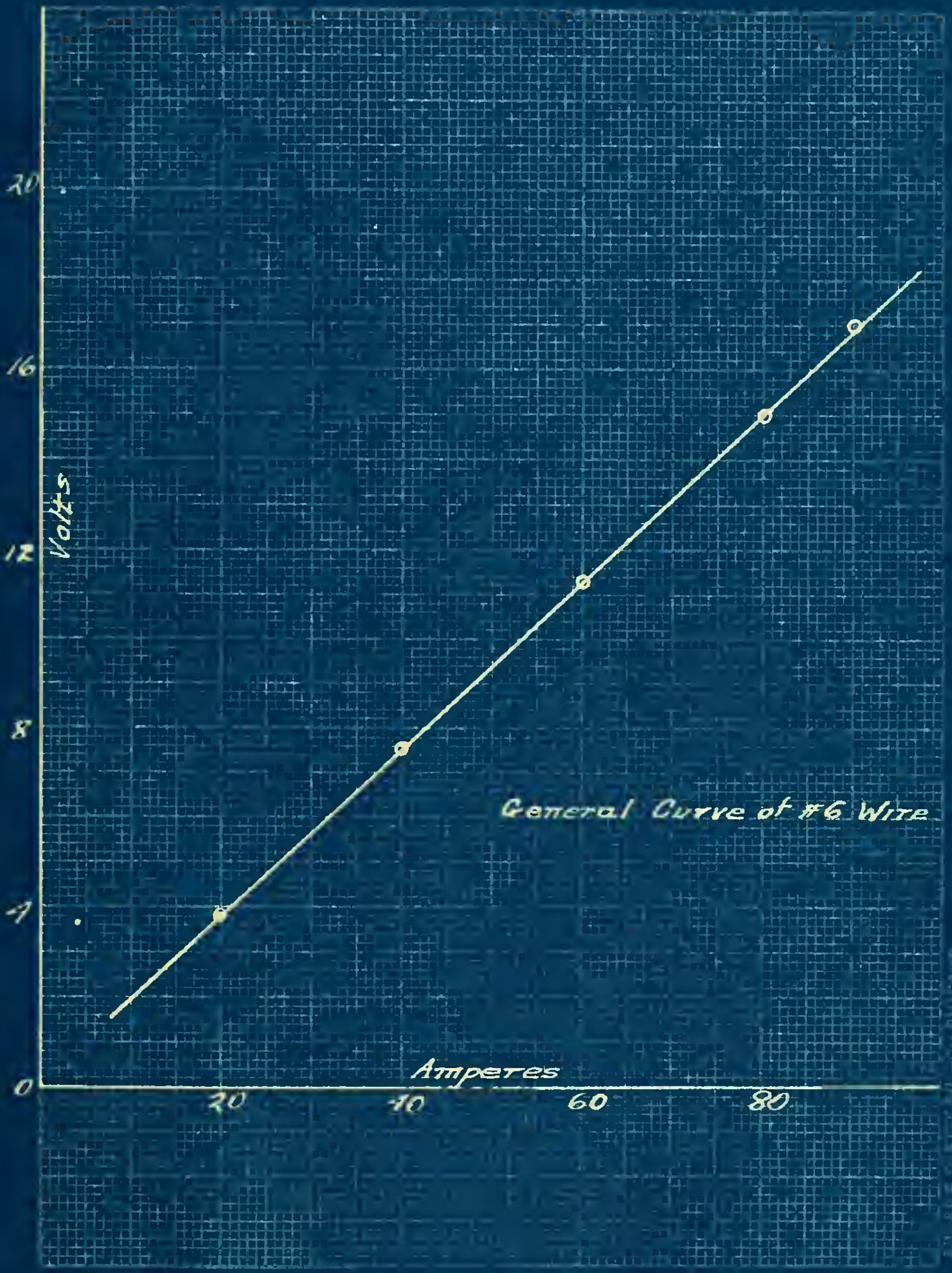
Volts
20
16
12
8
4
0
Amperes
20
40
60
80
100
Voltage Drop for #6
Wire at 30 cycles
⊙ = Points for Wire in Conduit
✶ = " " " " Air
EUGENE DIETZGEN CO., CHICAGO

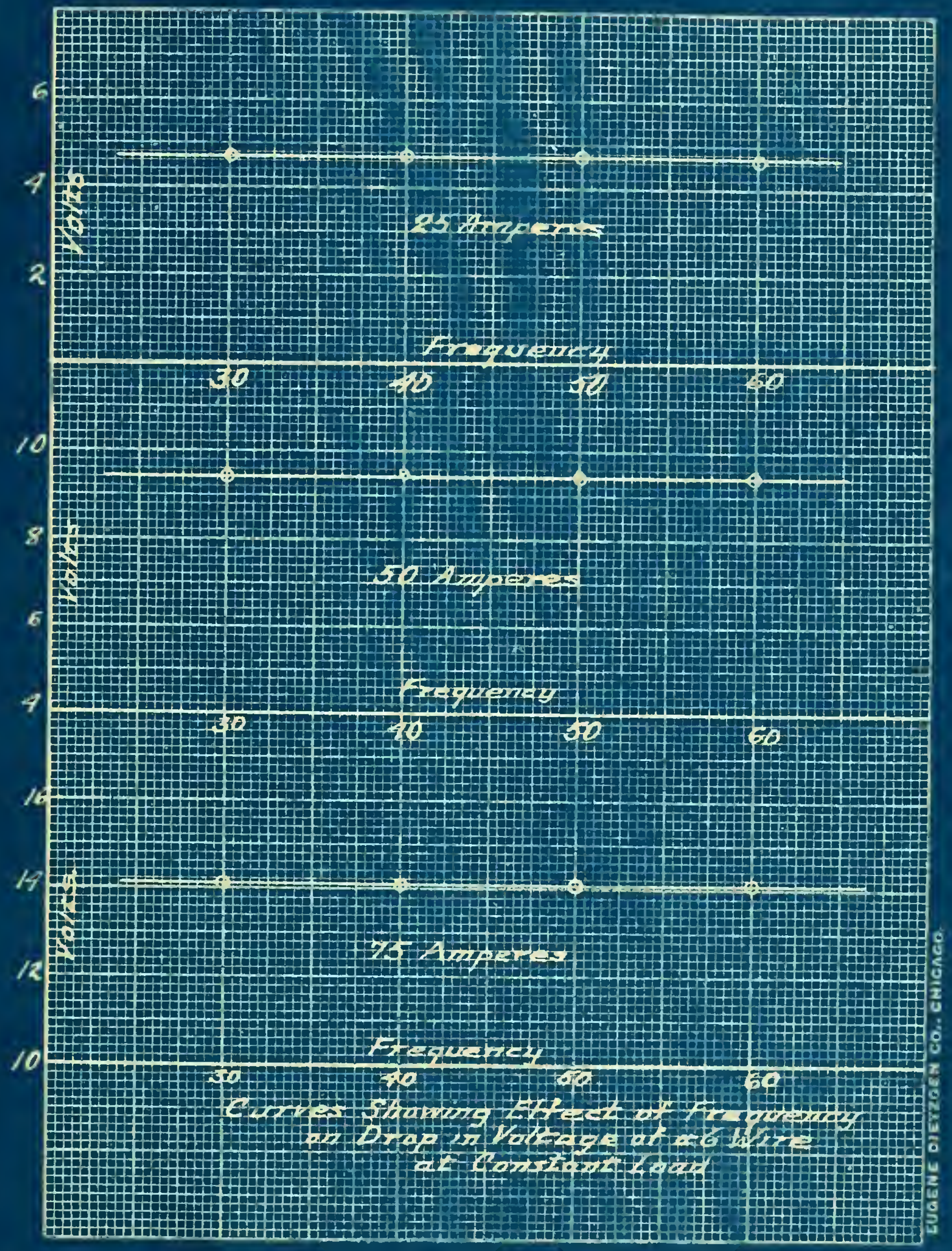

Volts
20
16
12
8
4
0
Amperes
20
40
60
80
100
Voltage Drop for #6 Wire
at 40 cycles
o = Points for Wire in Conduit
* = " " " " Air
EUGENE DIETZGEN CO., CHICAGO.



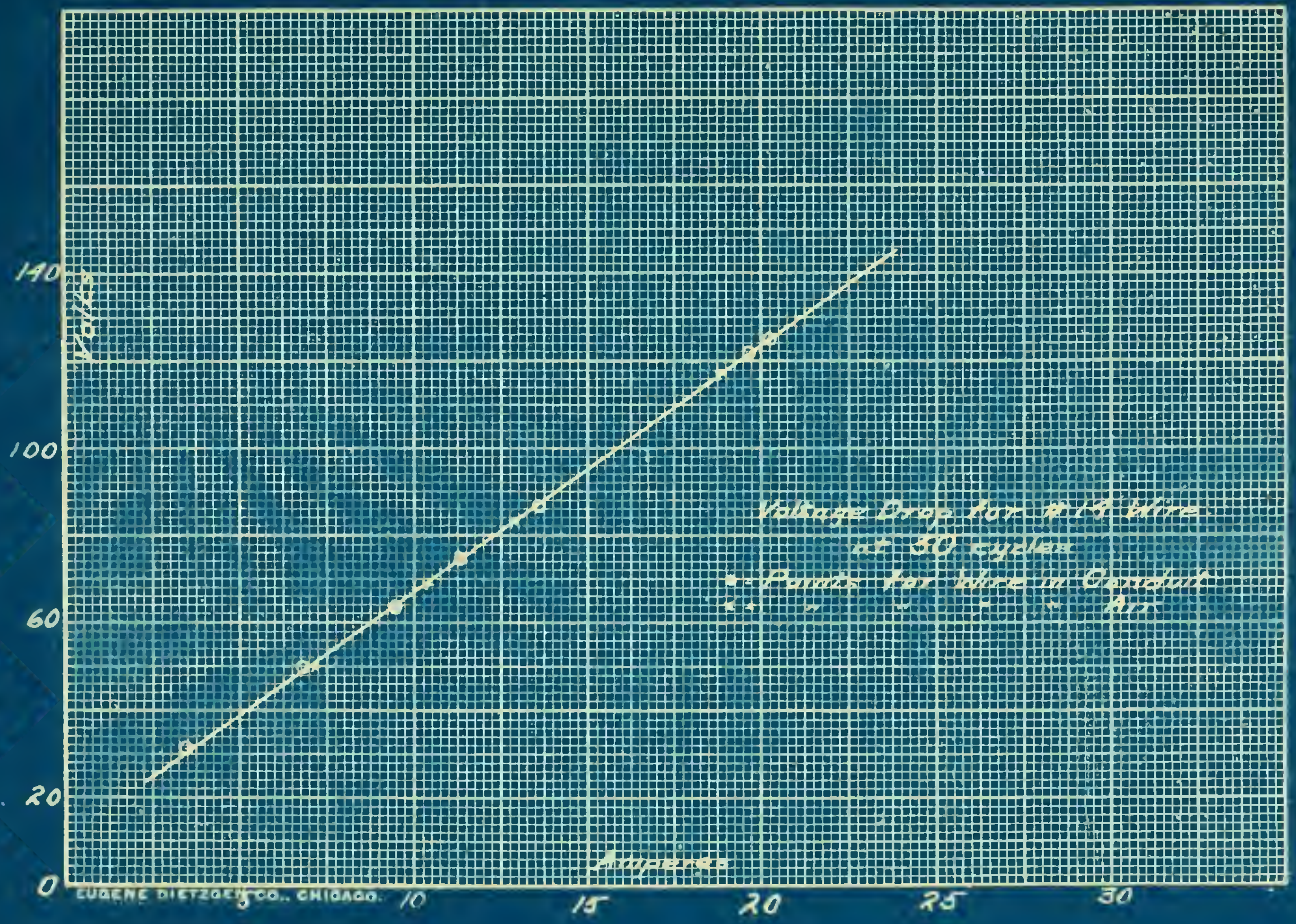
20
16
12
8
4
0
Volts
20
40
60
80
100
Amperes
Voltage Drop for #6 Wire
at 50 cycles
o-Points for Wire in Conduit
x-" " " " Air
EUGENE DIETZGEN CO., CHICAGO.

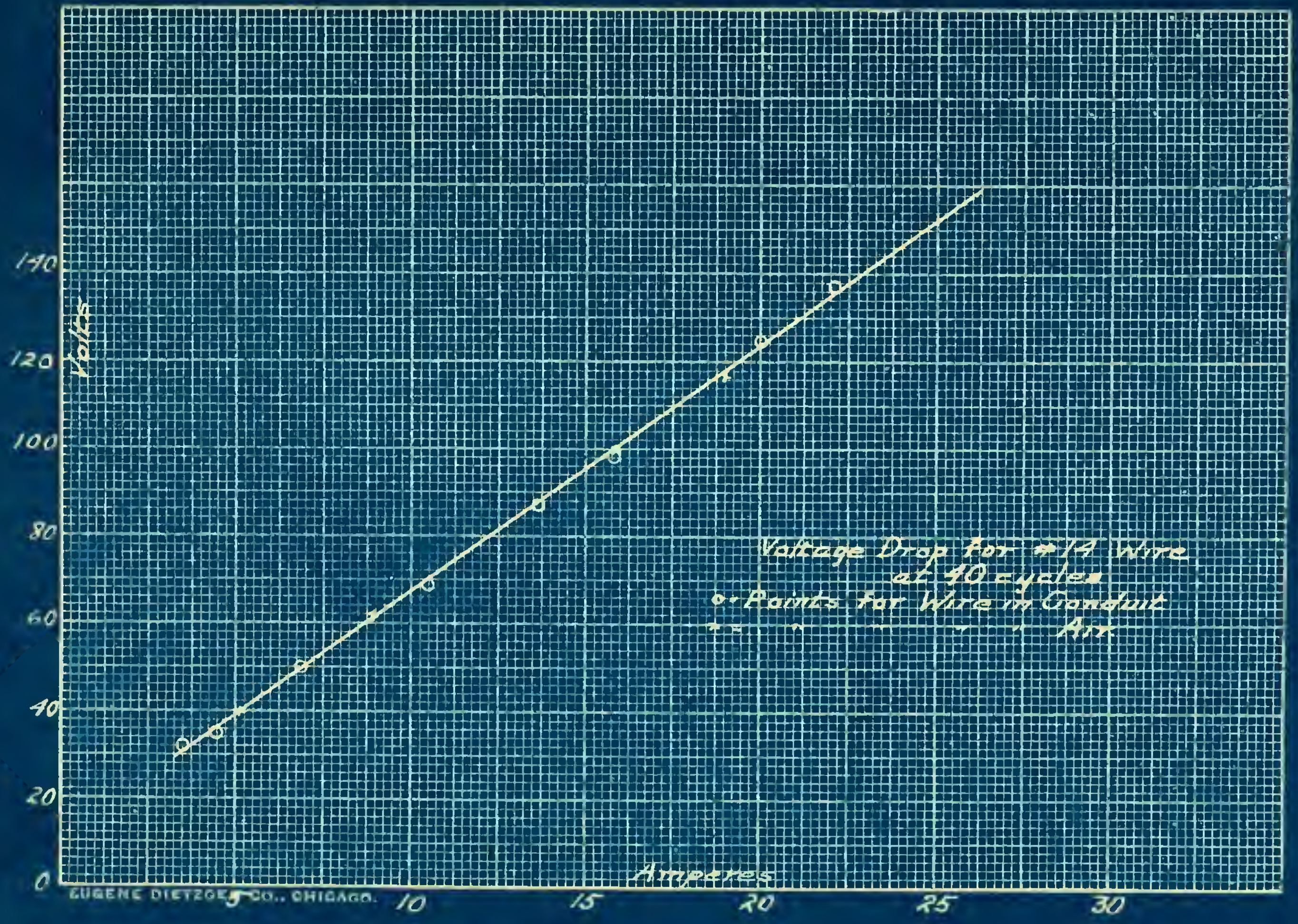

Voltage Drop for #6 Wire
at 60 cycles
○ - Points for Wire in Conduit
× - " " " " Air
Volts
20
16
12
8
4
0
Amperes
20
40
60
80
100
EUGENE DIETZGEN CO., CHICAGO

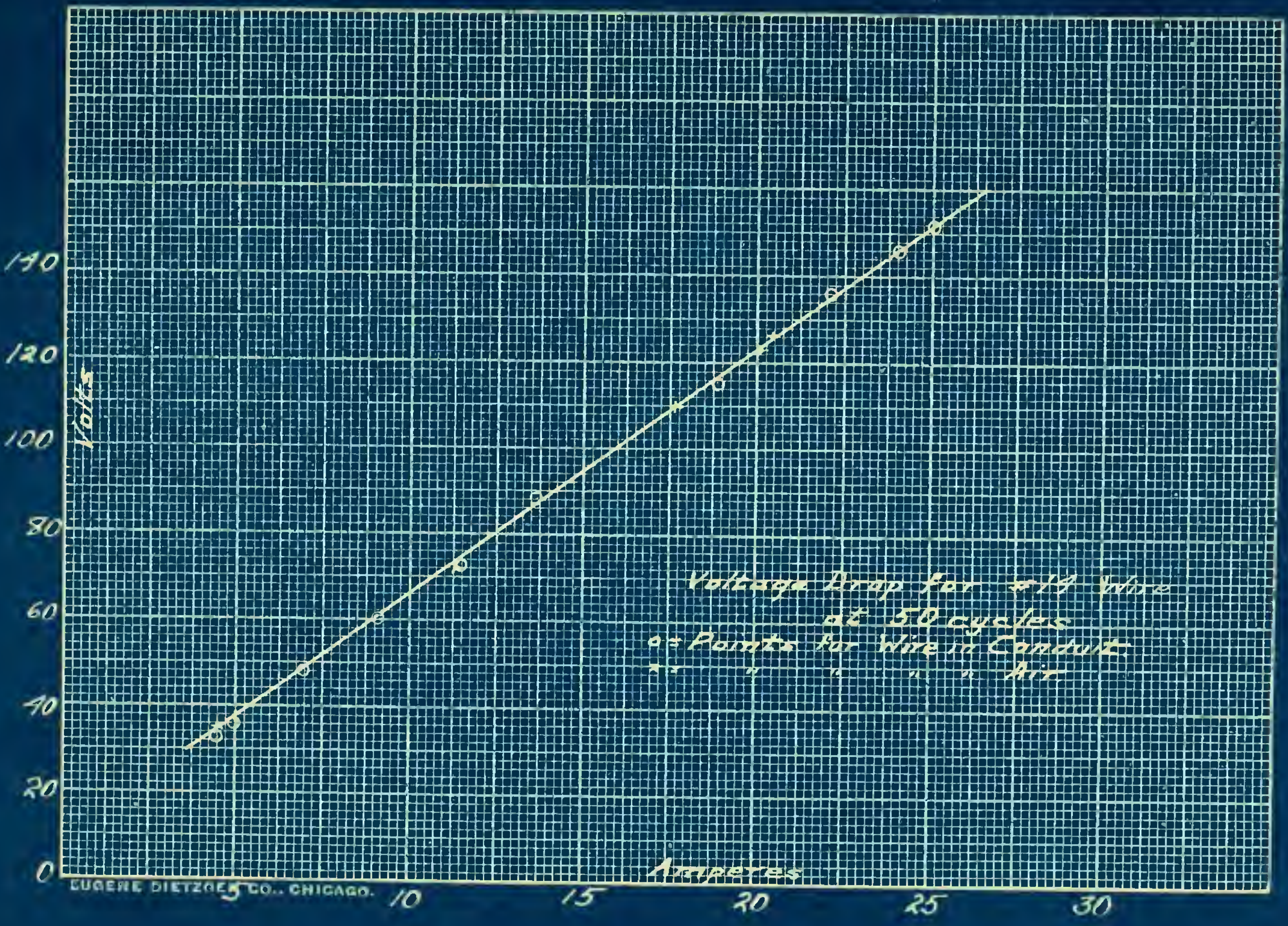

Volts
20
16
12
8
4
0
Amperes
20
40
60
80
General Curve of #6 Wire

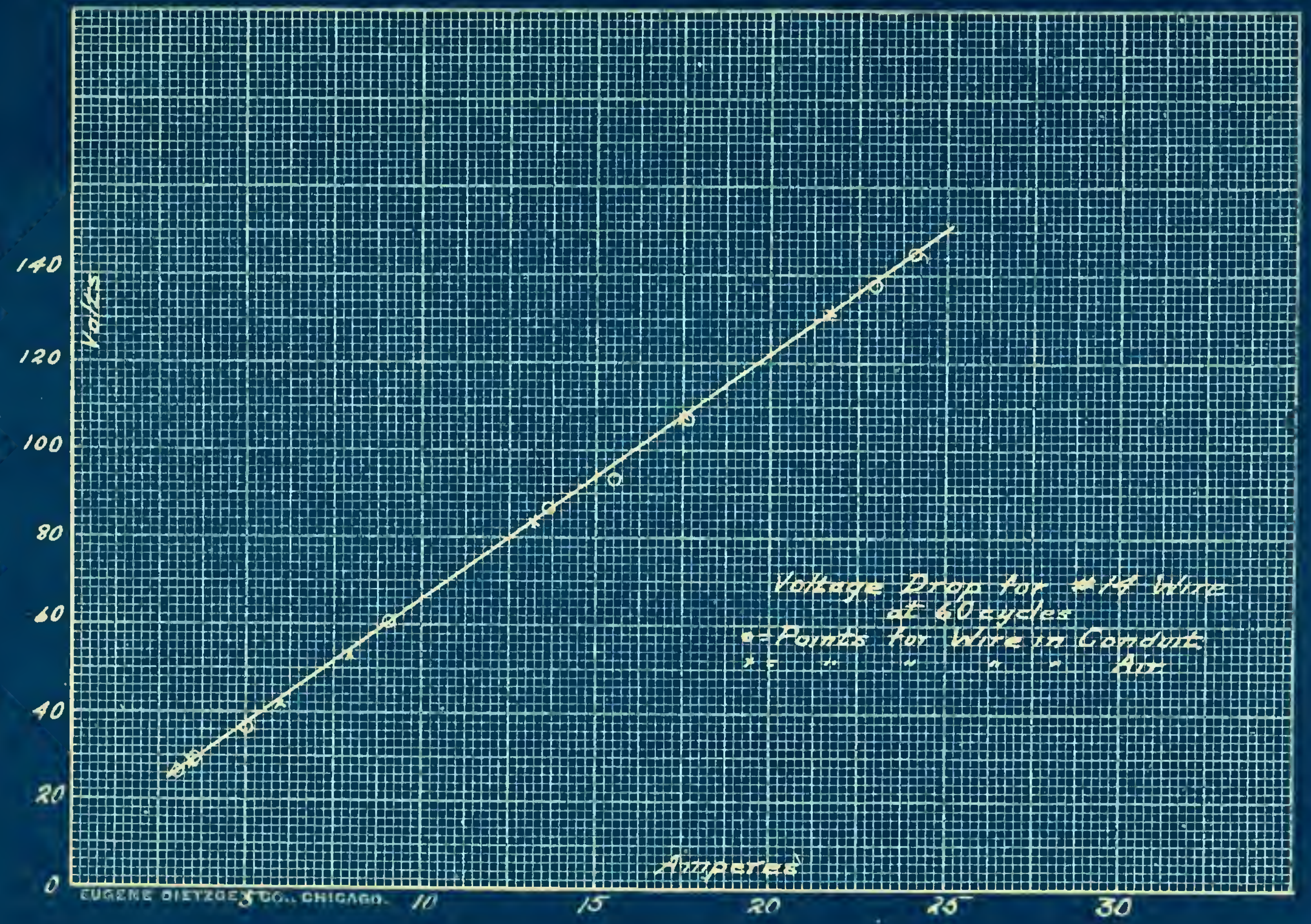


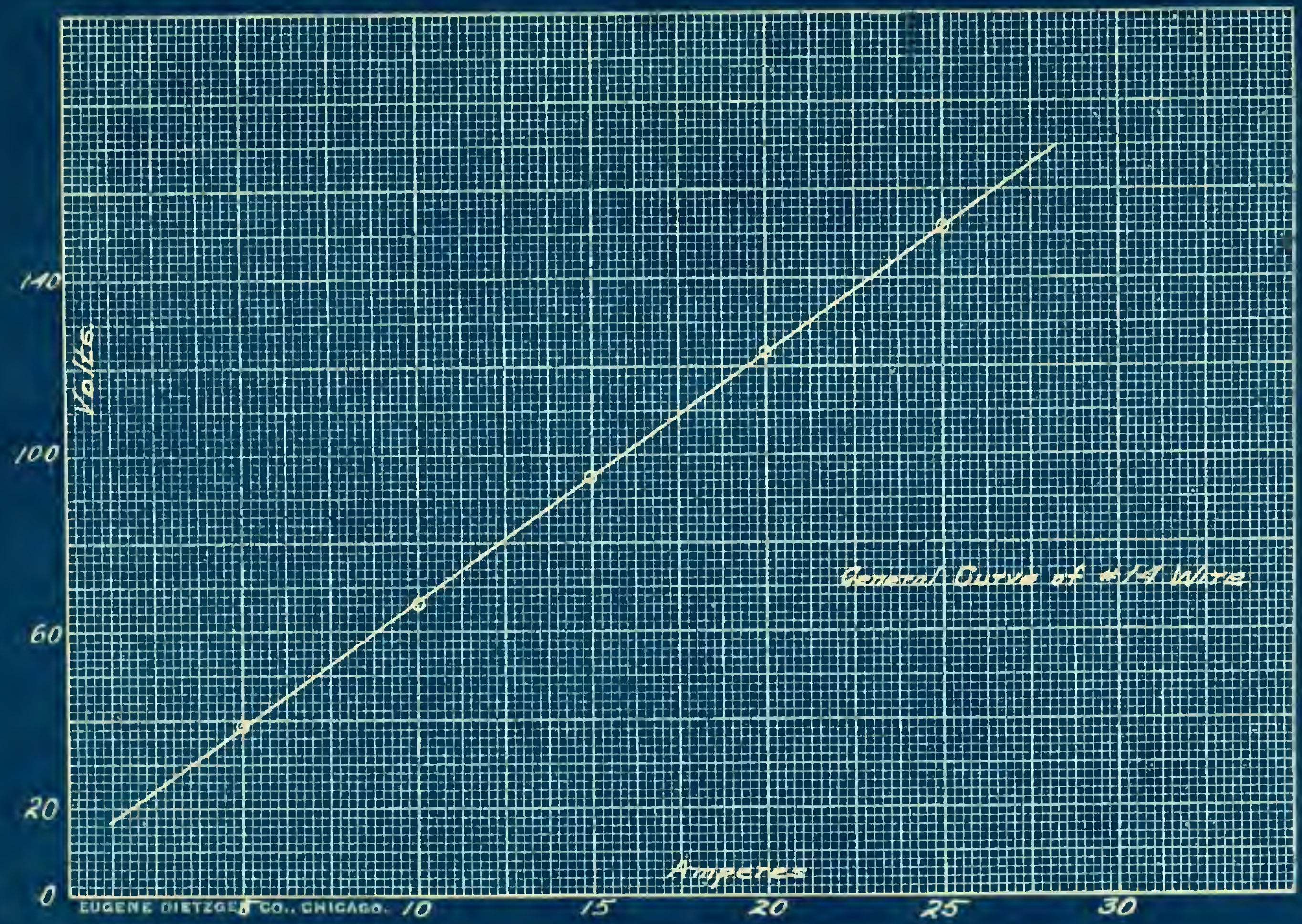
Curves Showing Effect of Frequency
on Drop in Voltage of a 6 Wire
at Constant Load

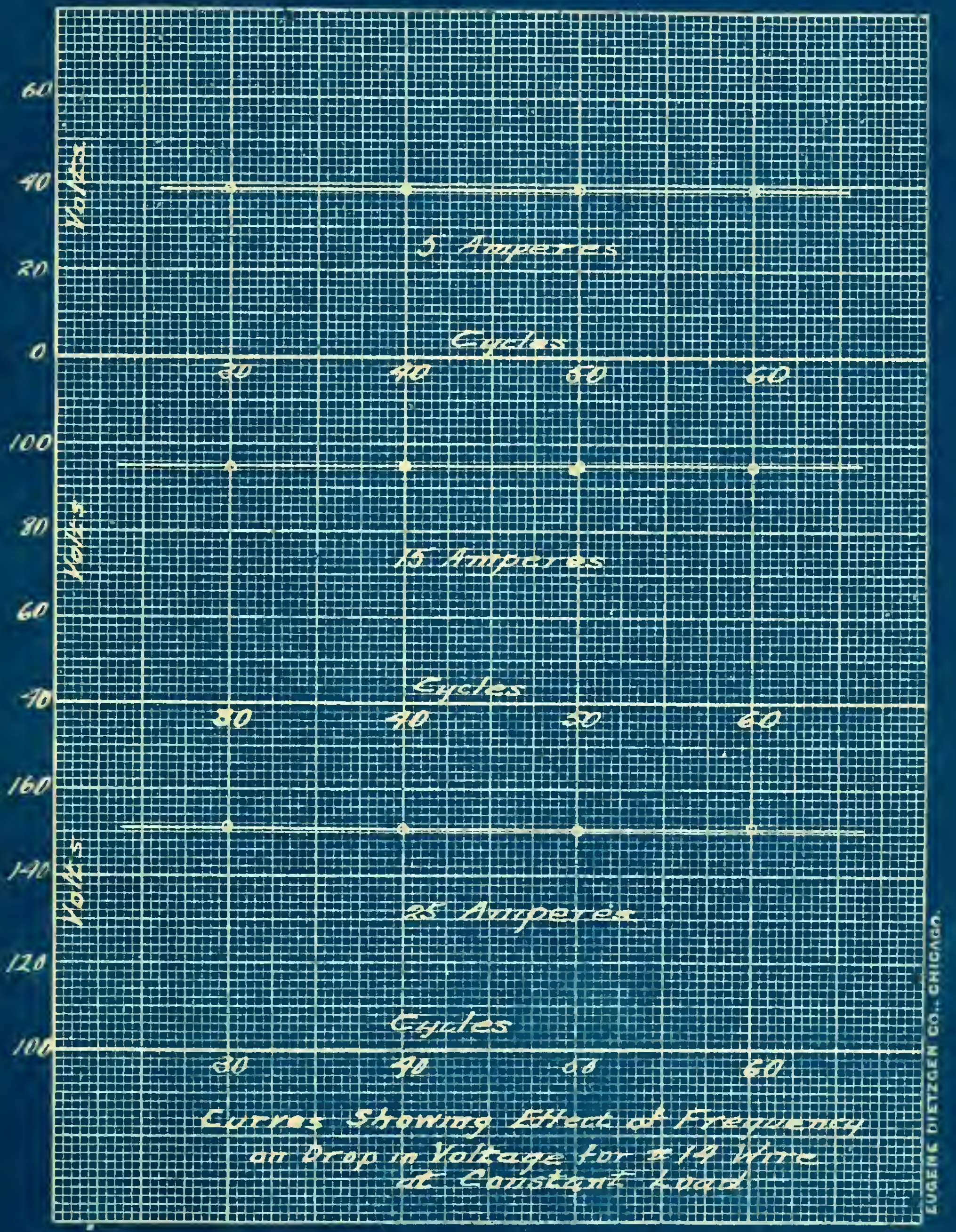

Voltage Drop for #14 Wire
at 50 cycles
• - Points for Wire in Conduit
× - " " " " Air
Volts
Amperes
0
20
60
100
140
10
15
20
25
30
EUGENE DIETZGEN CO., CHICAGO.


Voltage Drop for #14 Wire
at 40 cycles
o - Points for Wire in Conduit
+ - " " " " Air
Volts
140
120
100
80
60
40
20
0
Amperes
5
10
15
20
25
30
EUGENE DIETZGEN CO., CHICAGO.

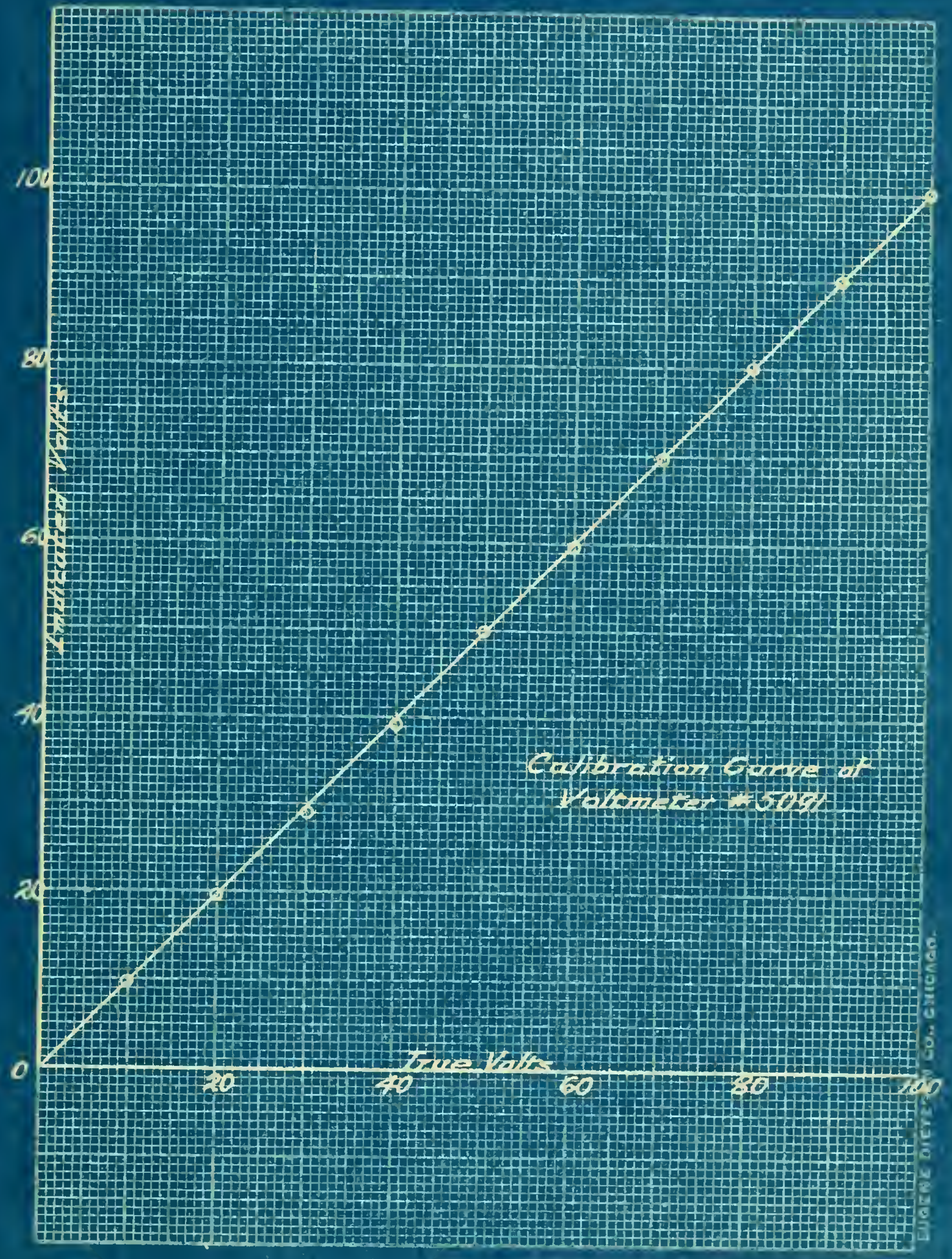

Voltage Drop for #14 Wire
at 50 cycles
o = Points for Wire in Conduit
x = " " " " Air
Volts
140
120
100
80
60
40
20
0
Amperes
5
10
15
20
25
30
EUGENE DIETZGEN CO., CHICAGO.

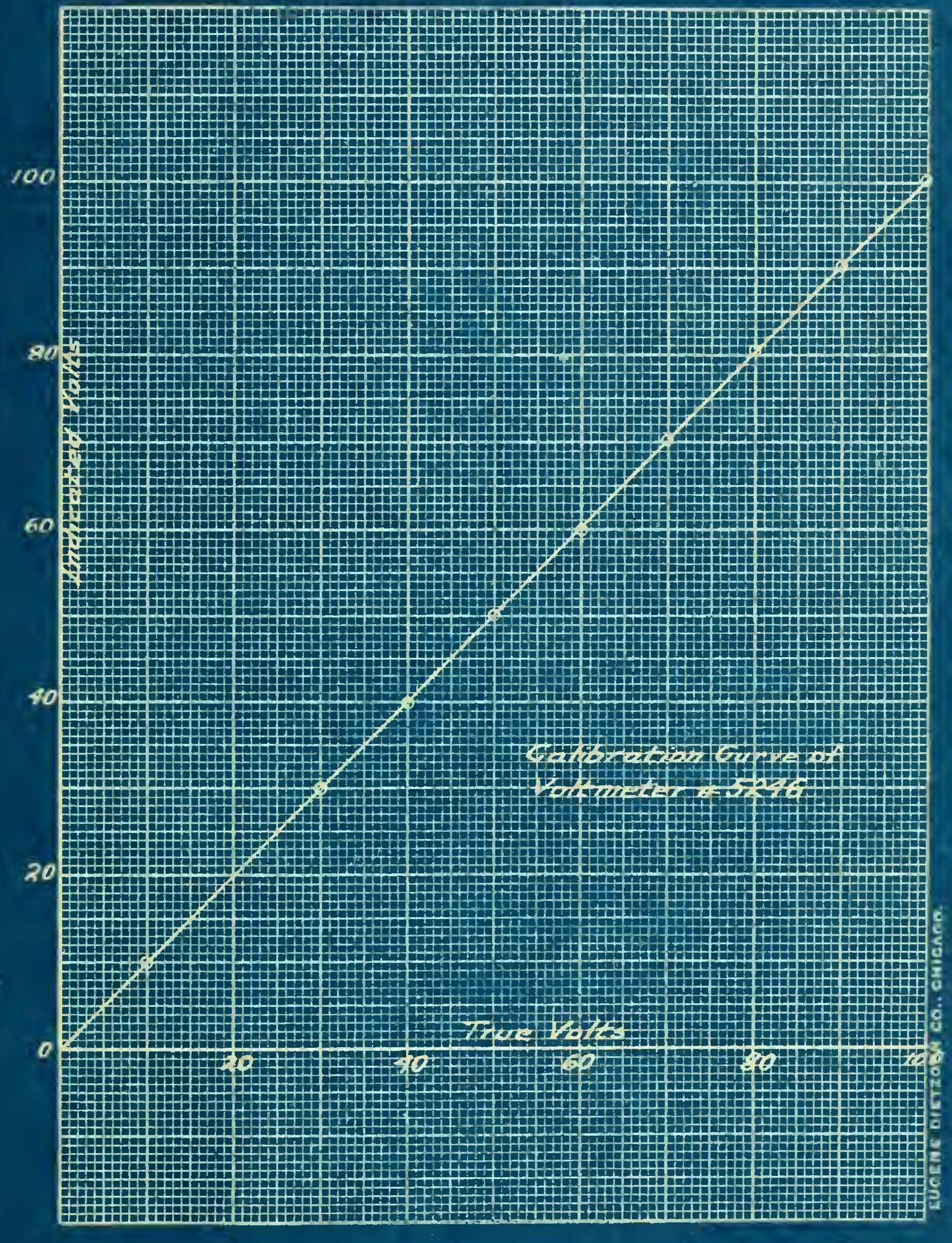

Voltage Drop for #14 Wire
at 60 cycles
○ = Points for Wire in Conduit
× = " " " " Air
Volts
0
20
40
60
80
100
120
140
Amperes
5
10
15
20
25
30
EUGENE DIETZGEN CO., CHICAGO.

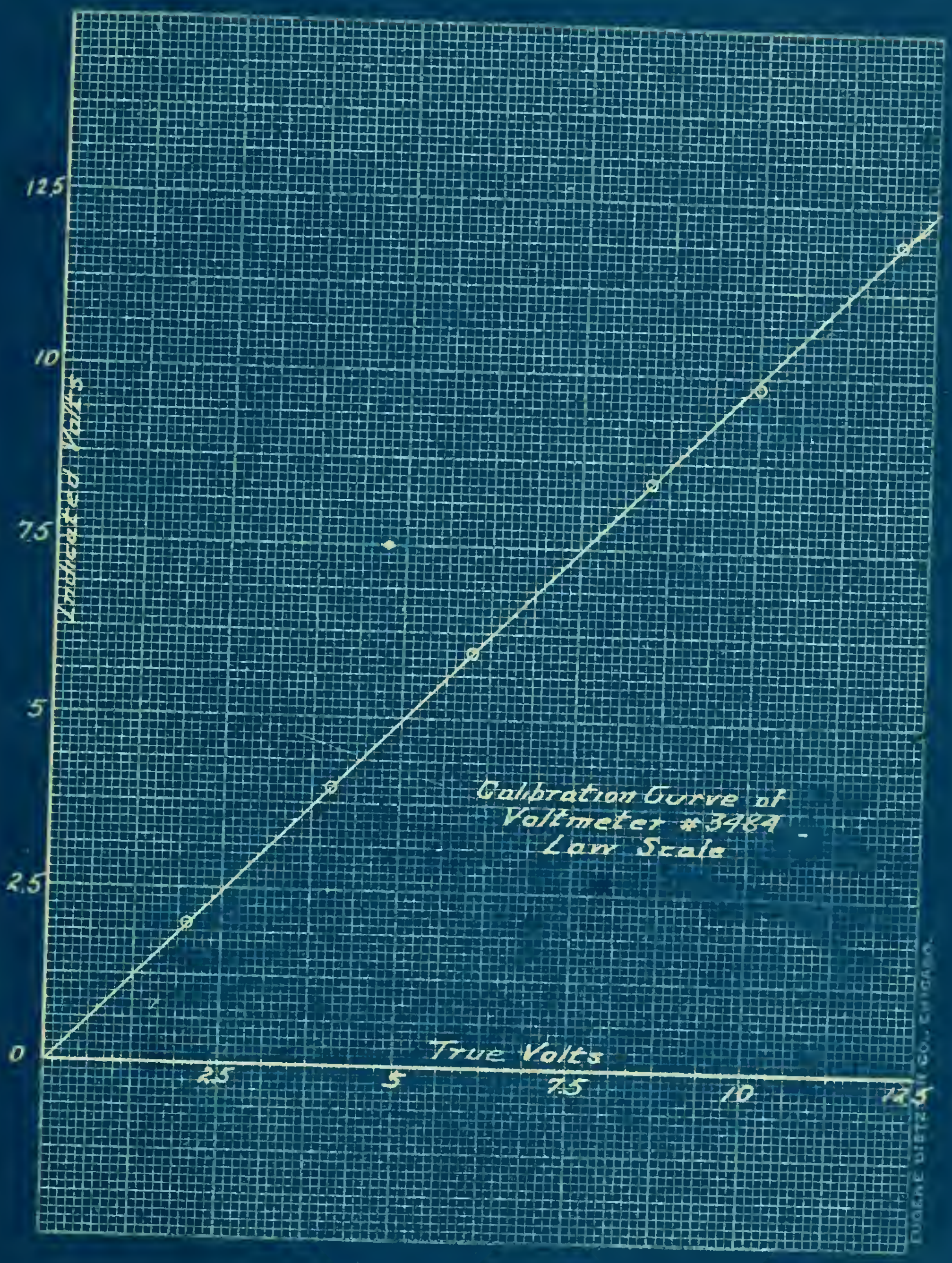

General Curve of #14 Wire
Volts
140
100
60
20
0
Amperes
10
15
20
25
30
EUGENE DIETZGEN CO., CHICAGO.

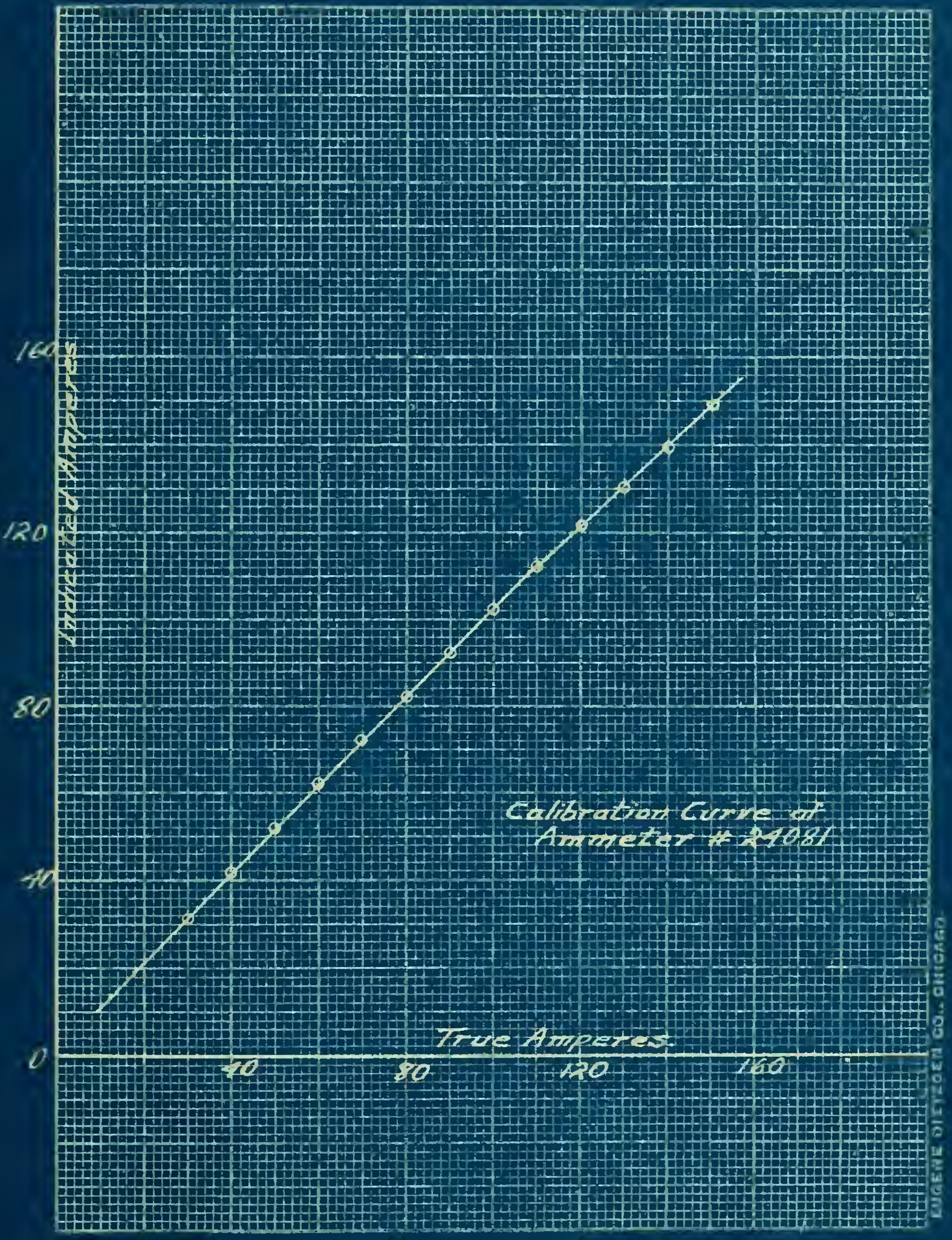


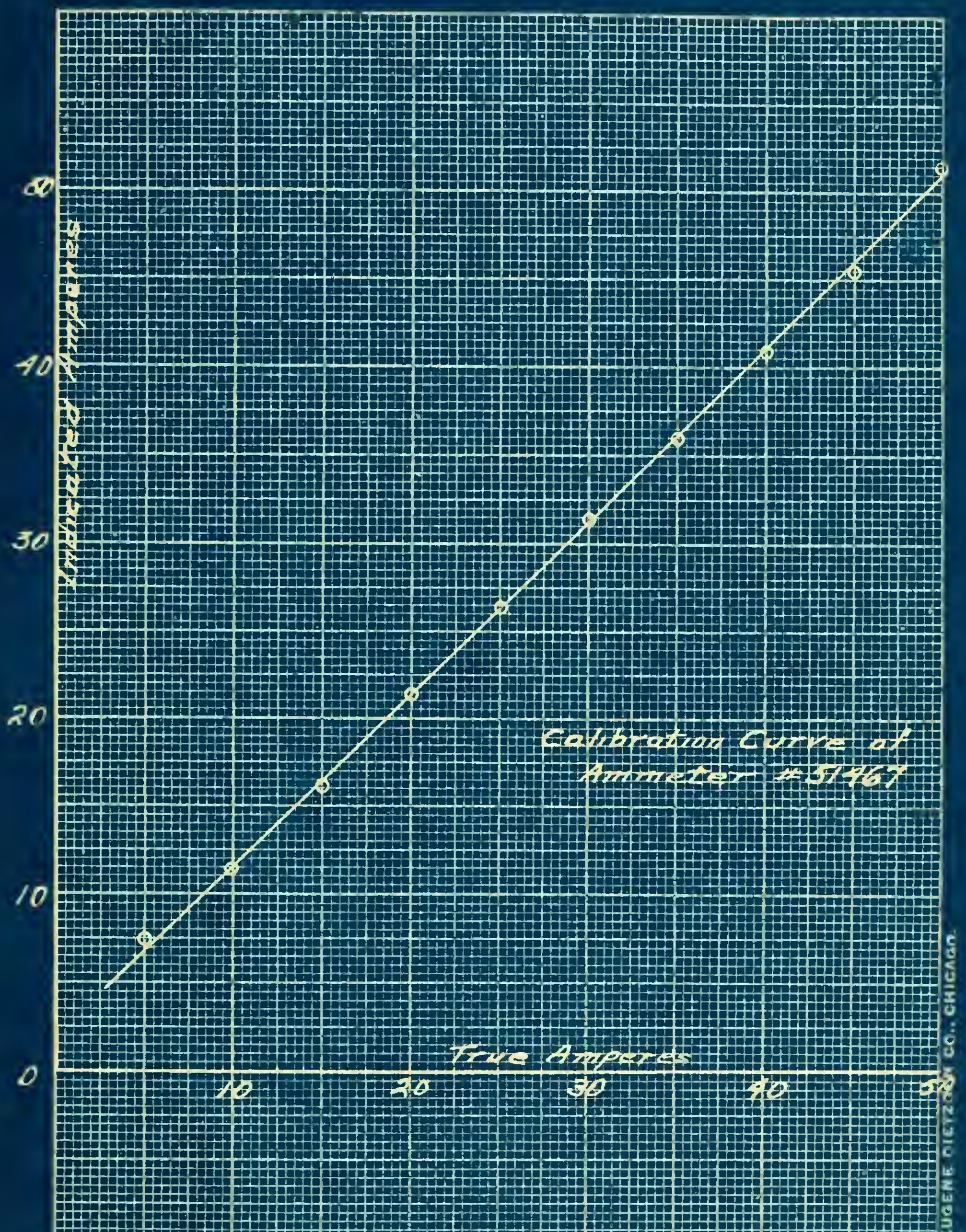
Curves Showing Effect of Frequency on Drop in Voltage for #14 Wire at Constant Load


Calibration Curve of
Voltmeter #5091
Indicated Volts
True Volts
0
20
40
60
80
100
20
40
60
80
100
EUGENE DIETZGEN CO. CHICAGO.


Indicated Volts
100
80
60
40
20
0
True Volts
20
40
60
80
100
Calibration Curve of
Voltmeter # 5246
EUGENE DIETZGEN CO., CHICAGO.


Calibration Curve of
Voltmeter #3484
Low Scale
Indicated Volts
True Volts
0
2.5
5
7.5
10
12.5
2.5
5
7.5
10
12.5
EUGENE DIETZGEN CO. CHICAGO


Calibration Curve of
Ammeter # 24081
Indicated Amperes
True Amperes
0
40
80
120
160
40
80
120
160
EUGENE DIETZGEN CO. CHICAGO



Calibration Curve of
Ammeter #51467